CHAPTER 11

CHILLED WATER SYSTEMS

11-1. Chilled water systems description

A chilled water system is a means by which heat, generated in a space or by a process, is conveyed from that space and ultimately released to the outside. This chapter is intended to acquaint the facility operator with chilled water systems and identify a minimum level of maintenance activities that must be performed to maintain a chilled water system for continuous day-to-day operation. Each chilled water system is designed to transfer heat by the most efficient and cost-effective method. While there is no right way to design a chilled water system, chilled water systems have common characteristics and use common types of components. Due to these differences in chilled water systems, the individual chilled water system equipment manufacturer's directions regarding maintenance practices take precedence over any guidance provided in this chapter.

a. System functions. Basically, a chilled water system circulates the chilled water through a loop piping system. Pumps force the water from the water chiller through the heat transfer components and back to the chiller via the piping system. Heat is transferred to the chilled water as it circulates through the heat transfer device that causes the temperature of the chilled water to increase. The portion of the system that supplies the water from the chiller to the heat transfer equipment is typically designated the chilled water supply system. Once the water is through this heat transfer equipment, the piping system delivering it back to the chiller is termed the chilled water return system.

b. Piping systems. There are two common types of chilled water piping systems: two-pipe and dual-temperature, with numerous variations of each. Two-pipe systems for comfort air conditioning typically operate with a design supply temperature of 40 to 55^{o}F and a system pressure of approximately 125 psi. Antifreeze or brine solutions may be used for chilled water systems (usually process applications) that require supply temperatures below 40^{o}F. In addition, well water type chilled water systems can use supply temperatures of 60^{o}F or higher. Dual-temperature systems are a combined water heating and cooling system that circulate hot and/or chilled water to heat or cool with common piping and terminal heat transfer apparatus. This chapter will consider two-pipe chilled water systems that supply 40 to 55^{o}F supply water only; however, much of the information presented in this chapter will apply to dual-temperature systems as well.

11-2. Chilled water systems major components

Chilled water systems are generally comprised of the following major system components.

a. Chillers. The most common chilled water air-conditioning system is a single compressor and refrigerant circuit using a water-cooled condenser. It is relatively simple and compact. Compression type refrigeration liquid chilling equipment ranges in size from quite small to those with capacities in the thousands of tons (1 ton equals 12,000 BTU per hour of cooling). The three categories of chillers that will be discussed in this chapter are those which use reciprocating compressors, centrifugal compressors, and rotary screw type compressors. Control of water chillers is typically based on the return water temperature. The return water temperature indicates the cooling load in the facility at any given time. The warmer the chilled water return temperature, the larger the facility cooling loads. Occasionally, the chiller is controlled by the leaving water (supply) temperature. This is typical for process chilled water applications. In this case, the rotary screw compressor or the centrifugal compressor will usually respond best and will provide modulating control to meet the load.

(1) Reciprocating type chiller compressors are available in capacities from about 2 to 200 tons. Reciprocating water chillers may have one, two, or more compressors, each of which is matched to a separate tube circuit in a common shell, and each with its own expansion valve, service valves, dryer, piping, and controls. The compressors may be piped to use a common water-cooled condenser or may each have their own water-cooled condensers. Chillers are also built with air-cooled condensers as part of a package for outdoor use, or can be built for use with a remote air-cooled condenser or an evaporative condenser. The principles of operation of all reciprocating compressors are much the same. Suction gas (from the evaporator) is drawn into the compressor through the suction shutoff valve to the suction chamber and on through a suction filter. The filter separates the lubricating oil from any liquid refrigerant that is mixed with the refrigerant gas. Since reciprocating compressors are made to pump refrigerant gas only, any liquid refrigerant must be separated from the gas to keep from doing any damage to the compressor valves. The gas then flows through the crankcase and then to the cylinders. The piston in the cylinder compresses the refrigerant that is discharged through the discharge opening. Water chillers which use reciprocating type compressors are of three main groups: hermetic, semihermetic, and open direct drive type.

(a) A hermetic unit uses a hermetic compressor with the electric motor totally enclosed in the refrigerant atmosphere. The possibility of refrigerant leakage to the outside through a shaft seal is totally eliminated, and motor operating noise is subdued by the housing. Because this type of forced refrigerant cooling of the motor is very effective, smaller, less expensive motors can be used. The need for a heavy external base to preserve motor-compressor shaft alignment is eliminated. Hermetic machines are less expensive than external drive machines, have slightly greater power consumption, and are quieter. However, should the motor fail, the repair cost is higher, and the unit must be replaced with a like unit or sent back to the manufacturer for service. These compressors are used in most cases for a small refrigeration or air-conditioning system.

(b) The semihermetic compressor, like the hermetic type, has both the compressor and its drive motor in the same casing. The term "semihermetic" means that the case in which both the compressor and motor are sealed may be opened for service or repair.

(c) Open direct drive type compressors are those in which the crankshaft, which is fitted with a shaft seal, extends from the housing. They do not have a drive motor as an integral part, but the drive motor in most cases is placed on the same base with the compressor. The motor may be joined to the compressor with a direct drive coupling or belt drive.

(2) Centrifugal compressors which are used as part of many large refrigeration and air-conditioning systems move a large volume of refrigerant at low pressures. They are made in sizes as great as 10,000 tons. The only wearing parts in a centrifugal compressor are the main bearings and the main seals. However, hermetic type centrifugal chillers do not have main seals. All centrifugal compressors do not have pistons. In this type of compressor, the refrigerant gas from the evaporator is pulled through the suction line into the center of the impeller. The impeller which is rotating at a high speed forces the gas flow to the outside edge of the impeller and out the impeller housing. The hot, high-pressure refrigerant gas then flows to the condenser. A centrifugal compressor may have one or more stages. These stages may be in the same or in separate impeller housings.

(3) The rotary screw type compressor uses a mated pair of special helical rotors. They trap and compress the refrigerant gas as they revolve in an accurately machined compressor cylinder. The helical rotors are made with the male rotor having four lobes and the female rotor having six interlobe spaces.

The male rotor often drives the female rotor, but in some cases they are both gear-driven. These compressors are built in either external drive or semihermetic construction. They are used in larger systems that range in size from 20 to 800 tons. These compressors are commonly used with R-134a, R-22, and R-717 (ammonia) refrigerants. An oil injection system is used that gives high-efficiency and smooth operation. As the lobe of the male rotor starts to unmesh from an interlobe space of the female rotor, a void is made and gas is drawn in through the inlet port. As the rotors continue to turn, the interlobe space increases in size and more gas flows into the compressor. Just prior to the point at which the interlobe space leaves the inlet port, the entire length of the interlobe is filled with refrigerant gas. As rotation continues, the trapped gas in the interlobe space is moved circumferentially around the compressor housing at a constant pressure. Further rotation starts the meshing of another male lobe with the female space on the suction end and progressively compresses the gas in the direction of the discharge port. Thus, the occupied volume of the trapped gas within the interlobe space is decreased, and the gas pressure as a result increases. As this gas is discharged, a fresh charge of refrigerant is drawn through the inlet on the opposite side.

b. Water chiller auxiliary systems. Auxiliary systems used to enhance chiller performance and to aid maintenance activities include the following.

(1) Purge units are required for centrifugal liquid machines using low pressure refrigerants (such as R-123), because evaporator pressure is below atmospheric pressure. If a purge unit was not used, air and moisture would accumulate in the refrigerant over time. These noncondensables drastically reduce the capacity and efficiency of the chiller operation. A purge unit is designed to prevent the accumulation of noncondensables and ensure internal cleanliness of the liquid chiller. Purge units may be manual or automatic, compressor-operated, or compressorless.

(2) A refrigeration transfer unit may be provided for centrifugal liquid chillers using refrigerants with a boiling point below ambient temperature at atmospheric pressure (R-134a, R-22). This system is used for adding and removing refrigerant to and from the chiller. The unit consists of a small reciprocating compressor with electric motor drive, a condenser (air-cooled or water-cooled), an oil reservoir, an oil separator, valves, and interconnecting piping.

(3) Air-conditioning equipment is generally selected on the basis of maximum design condition and is then expected to cope with a variety of conditions, some of which may force the equipment outside of its stable operating range. At light cooling loads, operating the chiller at its maximum capacity will cause frosting of the coil, excessive compressor cycling, and possible liquid carry-over. Hot gas bypass is a system that, at some predetermined partial loading, allows flow of hot refrigerant gas from the high-pressure side to the low-pressure portion of the refrigerant system. This reduces the condenser capacity to produce refrigeration, because the gas returned to the low-pressure side produces no useful cooling; instead it becomes an evaporator load. This enables the chiller to operate over a broader range of conditions and avoid freeze-ups and cycling problems.

c. Pumps. The type of pump used to distribute chilled water through the chilled water system varies with the system design. There are two basic types of pumps: positive displacement and centrifugal.

(1) Positive displacement pumps trap the liquid in internal cavities and move it from the inlet of the pump to the discharge. This action increases the velocity and pressure of the liquid which flows in the discharge pipe. Positive displacement pumps are rarely used in chilled water systems.

(2) Centrifugal pumps are the most commonly used pumps in refrigeration and air-conditioning systems and are classified by their mechanical features, installation arrangement, mounting position, and

method of connection to the electrical motor. figure 11-1 shows several types of centrifugal pumps. Centrifugal pumps have three main parts: a prime mover (typically electric motor), an impeller, and a body. The motor is often connected to the pump shaft by a flexible type coupling. Some centrifugal pumps are built with the motor and pump impeller on the same shaft. In all cases, the pump impeller is connected to the shaft and turns the same speed as the motor. The impeller is the part of the pump that causes the water to move through the pump body. Impellers vary widely in their construction. The centrifugal force that comes from the rotating impeller moves the water or other liquids through the channels that run between the vanes. The outward-moving water streams are directed by the volute in a single stream that flows out of the pump discharge. This action of the impeller builds up the pressure of the water at the pump outlet.

d. Expansion tanks. Expansion tanks are used in chilled water systems for two purposes. First, expansion tanks allow for thermal expansion of the chilled water that, if not for the expansion tank, could damage the piping system. Secondly, the expansion tank provides a location for makeup water to be admitted to the system. The expansion tank is connected to the chilled water system on the inlet (suction) side of the distribution pump(s) by a branch line. The makeup water line is typically connected to this branch line between the expansion tank and the main pump inlet pipe.

e. Control valves. Control valves are used in chilled water systems to control the flow of chilled water through the piping system. The control system positions the valve through a valve operator or actuator that is directly attached to the valve stem. The valve operator or actuator uses electricity, compressed air, or hydraulic fluid to move the valve stem through its operating range.

f. Thermal storage. Thermal storage is the temporary storage of high- or low-temperature energy for later use. The purpose of thermal storage is to lower overall energy costs by generating and storing cooling medium during periods when electrical rates are at their lowest (off-peak). This occurs typically during the night or during periods of light air-conditioning loads.

(1) There are two types of storage strategies: full storage and partial storage. In full storage systems, the entire cooling load for a design period of time is generated during the off-peak time and stored for use during the following design period. In partial storage systems, only a portion of the design period cooling load is generated and stored during the previous off-peak period. During the peak period, the cooling load is satisfied by simultaneous operation of the cooling equipment (chillers) and withdrawal from storage.

(2) There are two thermal storage system options available for large commercial and industrial cooling applications: chilled water storage and ice storage.

(a) Chilled water storage systems use conventional chillers, pumps, and piping systems. They also require large storage tanks for chilled water. In this system, chilled water is generated during off-peak periods and stored in a storage tank. During peak cooling periods, the stored chilled water is pumped from the tank to the cooling equipment (air handler coils, etc.) and then returned to the storage tank.

(b) There are several types of ice storage systems that are used to store thermal energy. Ice storage typically has the advantage over chilled water storage in that it requires less space.

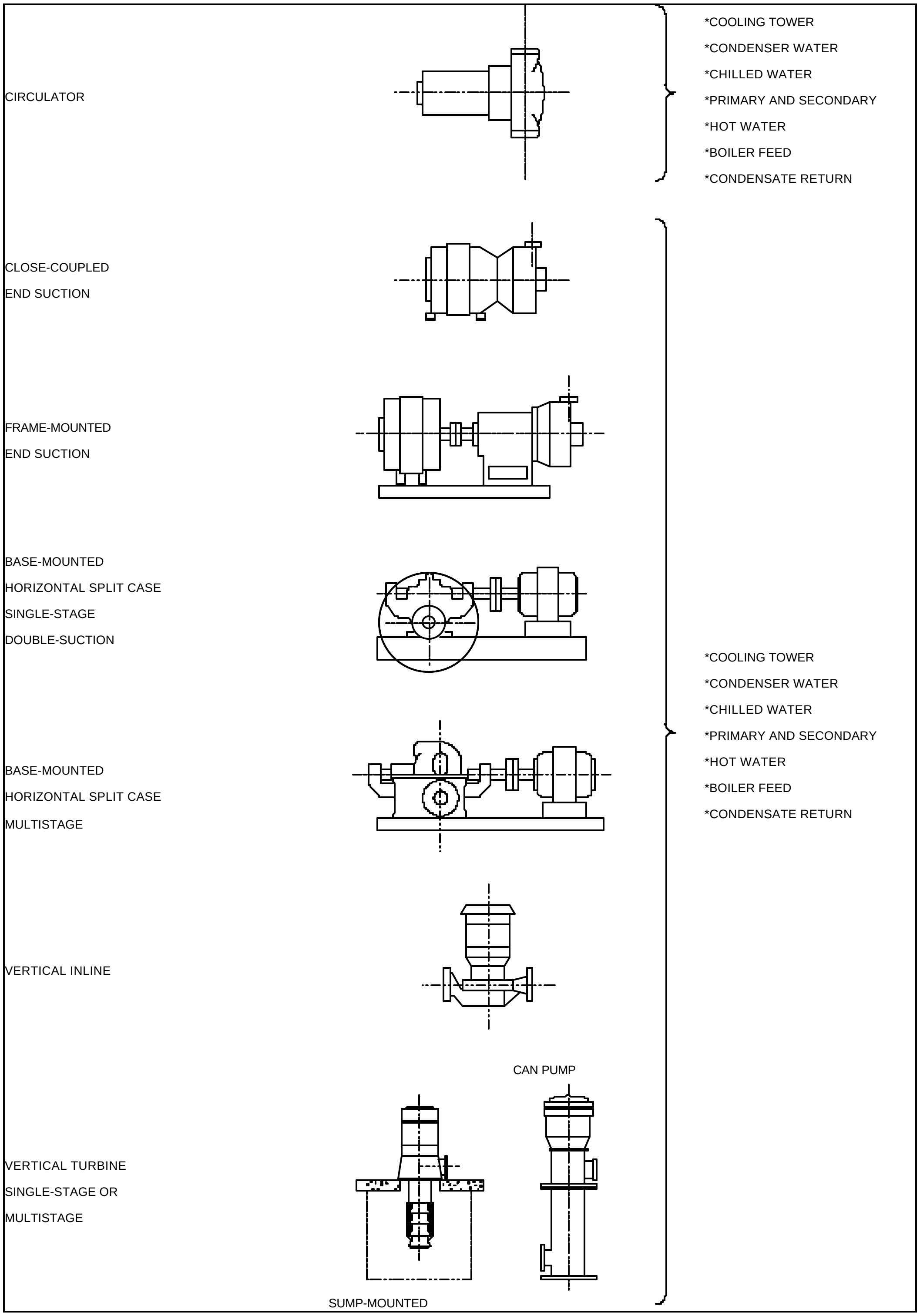

Figure 11-1. Variations of centrifugal pumps

g. Heat exchangers. A heat exchanger is any device that affects the transfer of thermal energy from one fluid to another. In the simplest exchangers, the hot and cold fluids mix directly; more common are those in which the fluids are separated by a wall. Common heat exchangers include the flat-plate, shell-and-tube, and cross-flow types. A double-pipe heat exchanger, the simplest form of the shell-and-tube, can have the fluids both flow in the same direction. It is referred to as a parallel-flow type. If they flow in opposite directions, it is referred to as a counter-flow type. A shell-and-tube exchanger may also have several tubes, two-passes, and baffles. In cross-flow heat exchangers, the fluids flow at right angles to each other. The evaporator and condenser sections of water chillers are examples of shell-and-tube type heat exchangers that are an integral part of the water chiller package. Heat exchangers are also designed and used as stand-alone thermal heat transfer devices in chilled water systems, heating water systems, and steam systems.

h. Strainers. Strainers are defined as closed vessels with cleanable screen elements designed to remove and retain foreign particles down to 0.001 inch diameter from various flow fluids. A strainer differs from a filter in that strainers trap particles that are typically visible to the naked eye. Strainers are typically installed in chilled water systems on the inlet (suction) side of the distribution pumps.

i. Air separators. All chilled water systems use air separators to remove air (gas) bubbles that have become entrained in the water. One type of air separator is simply a tank constructed so that the chilled water inlet is not in a direct line with the outlet from the tank. The diameter of the tank is large compared to the chilled water piping. As the chilled water enters the expansion tank, the flow is slowed down considerably. This slowing of the flow, together with the change in direction of the chilled water flow, allows the air to rise to the surface of the tank or into the expansion tank to be vented. A more common type of air separator is a mechanical type air separator with a tangential entry that causes the chilled water to spin down from an upper entry to a lower discharge. The resulting turbulence enhances the air separation. Tangential entry mechanical separators generally require less space than tank type separators, but require that the circulating pump be capable of producing higher differential pressures. The air separator is typically installed in the chilled water supply piping between the chiller and the distribution pump. Air separators should be fabricated, tested, and certified in accordance with the appropriate sections of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code for unfired pressure vessels.

j. Valves. Valves installed in the chilled water system are used to control water flow and to isolate equipment for ease of maintenance. Most valves in a chilled water system are manually operated with a handwheel or lever operator.

(1) Valves are rated in terms of saturated steam pressure; nonshock cold water, oil, or gas pressure (WOG); or both. Valve ratings are usually stamped or cast into the valve body. A valve with the markings "125" or "200 WOG" will operate safely at 125 psig of saturated steam or 200 psig of cold water, oil, or gas.

(2) Valves generally should be installed with the stem in the vertical up or horizontal position. Gate valves should be installed with the stem in the horizontal position and the bottom half of the valve disk opening in the direction of flow. Check valves are best-suited for horizontal installation, unless specifically designed for vertical installation. Special care must be taken when welding, soldering, or brazing valve end connections. All valve components not capable of withstanding the temperatures generated should be removed or cooled during installation. Valves are typically installed at the following locations.

(a) On the inlet and outlet connection of each piece of equipment, including chillers, pumps, reducing valves, control valves, tanks, coils, and other equipment that requires periodic maintenance.

(b) On the supply and return branch lines at the point of connection to the main supply and return piping headers.

(c) Drain valves are installed at low points in the water distribution system to facilitate draining of the system.

(d) Vent valves should be installed at all high points in the chilled water piping system for manual venting of air from the system and to help in the draining of the piping.

(3) The most common types of valves utilized in chilled water systems include gate, ball, butterfly, globe, check, and pressure regulating valves. The general characteristics of these valves are described below. Illustrations of these valves are located on figures 11-2 and 11-3.

(a) Gate valves are identified by a wedge-shaped disk that is raised to open or lowered to close the valve. Gate valves are intended to operate fully open or fully closed, and have very low resistance to flow in the open position, since the disk rises out of the flow path. The gate valve should not be operated in the partially open position, as this may cause vibration and premature wear on the disk. The gate valve may be used for shutoff service where a slow closure is acceptable and where an absolute bubbletight closure is not a critical consideration. Gate valves may be rising stem with outside screw and yoke (OS&Y), rising stem with inside screw, or non-rising stem. The rising stem type makes viewing of the valve position possible, while the non-rising stem type requires less clearance above the operator, since the stem does not rise from the body.

(b) Ball valves use a ball as the opening/closing mechanism to control fluid flow. The ball is rotated 90 degrees from full open to full closed; therefore, it is well-suited for applications which require quick or frequent opening and closing. The ball seals by fitting tightly against resilient seats located on each side of the ball. Ball valves are generally selected for on/off service and are most common in sizes 3 inches or less. Ball valves are available in three port sizes, including standard, full, and reduced port. Full port has the same opening size as the connecting pipe, standard port is usually one pipe size smaller than the valve size, and reduced port may be up to two pipe sizes smaller than the valve body size.

(c) Butterfly valves in the chilled water system are most common in the larger sizes due to the ease of operation, low cost, and superior shutoff characteristics. The butterfly valve usually consists of a wafer-shaped body with a rotating disk that closes against a resilient seat located within the valve body. Like the ball valve, a 90-degree rotation of the operating mechanism results in valve travel from closed to full open. The butterfly valve is well-suited for both on/off service or throttling service.

(d) Globe valves are primarily used for throttling service and are not well-suited for full flow applications due to the high resistance to flow designed into the valve. The standard valve consists of a round disk or tapered plug that seats against a round opening. Angle valves and needle valves are variations of the standard globe valve and use a similar method of closure. Unlike the gate and ball valves, globe valves must be installed in the proper direction of flow. Flow should enter through the disk seat and push up against the valve disk. Reverse installation will result in valve chatter, vibration, and premature valve failure.

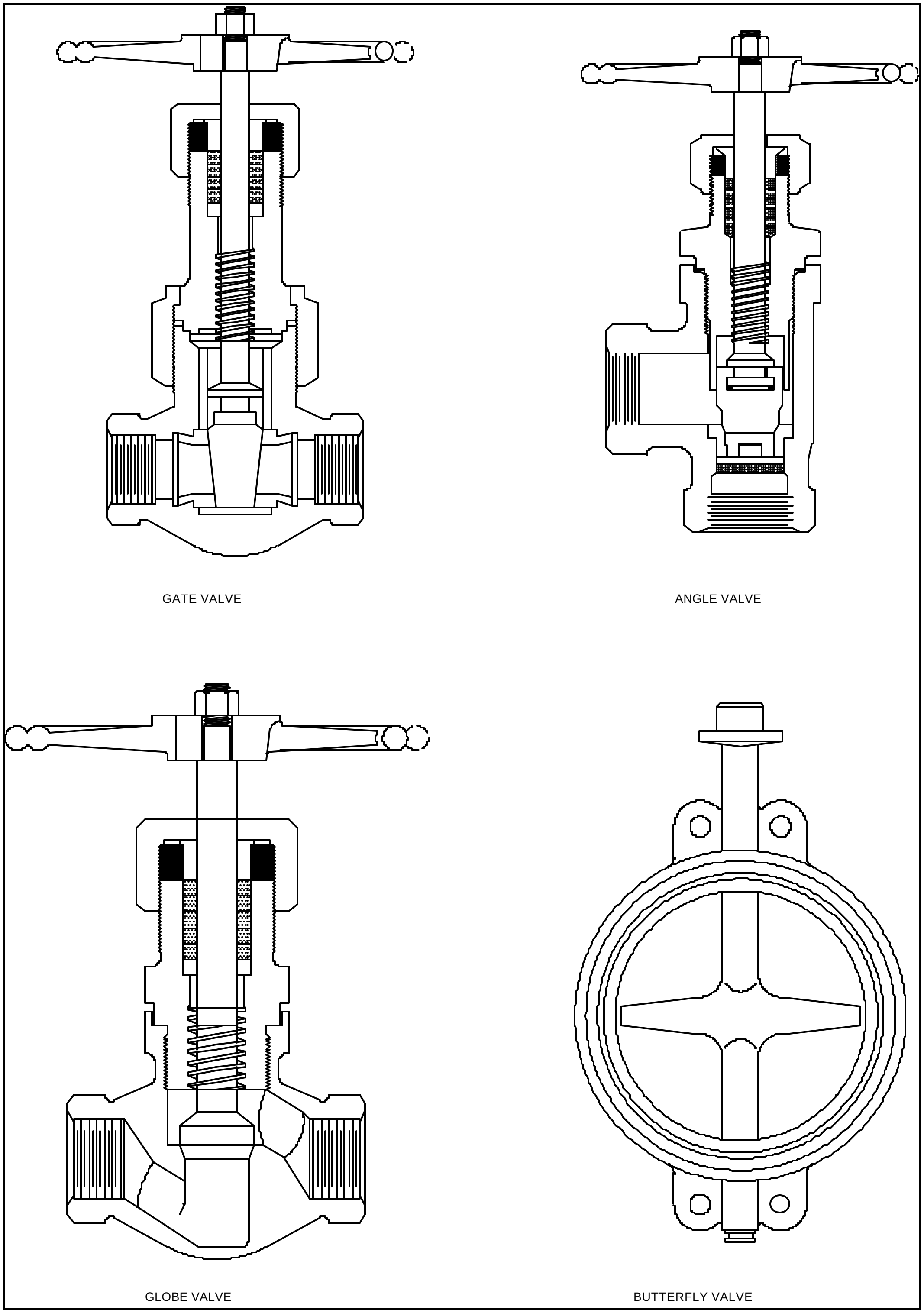

Figure 11-2. Typical valves used in water service(1)

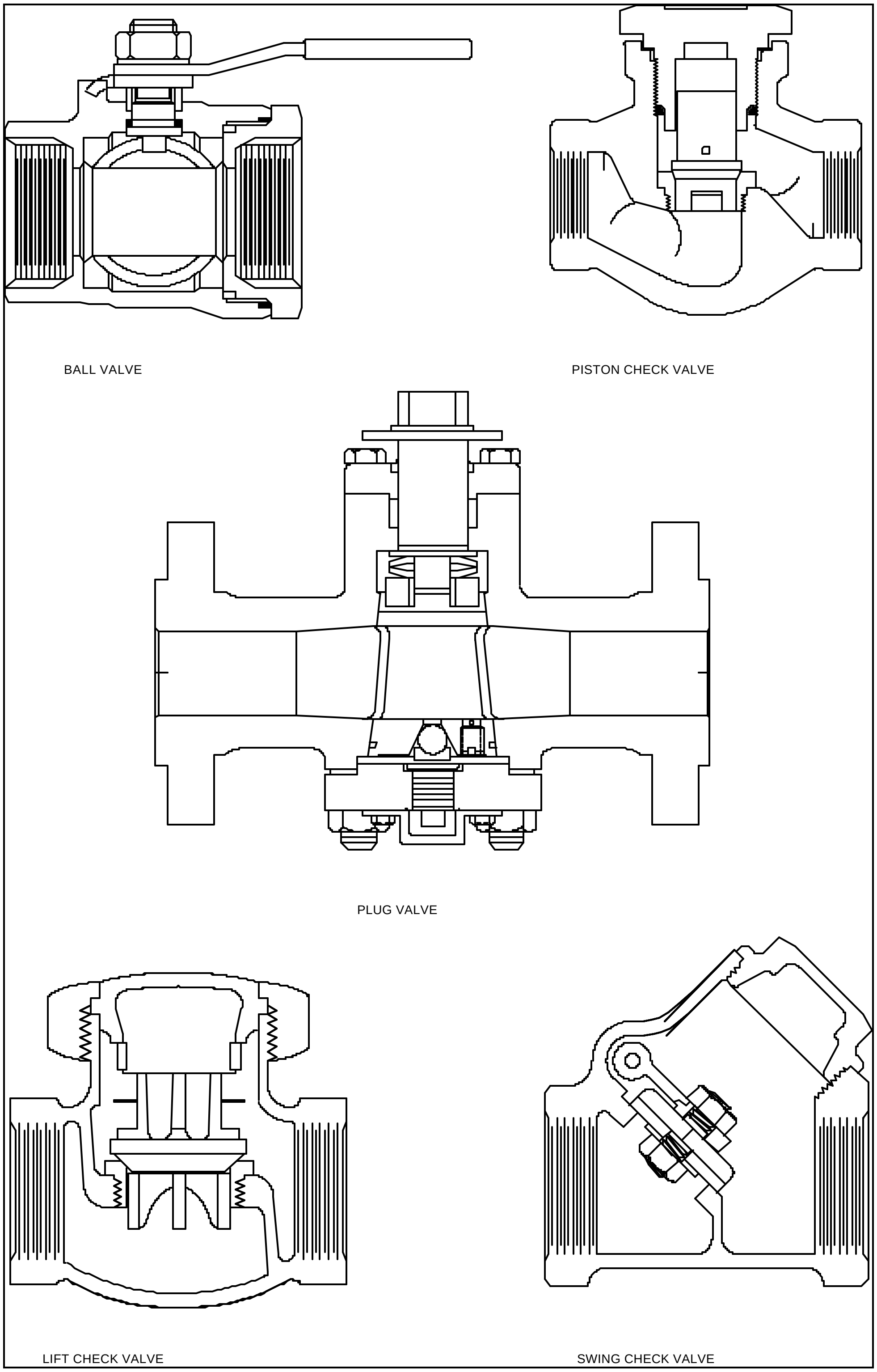

Figure 11-3. Typical valves used in water service(2)

(e) Check valves are used in the chilled water system to prevent reversal of flow at pumps and equipment, with swing checks and lift checks as the most common types. The swing check has a swinging disk that is held open by the fluid flow. Closure results from reverse flow and gravity acting on the disk. Lift check valves consist of a disk that is lifted by upward fluid flow. Reversal of flow pushes down on the disk, stopping flow. The swing check valve has less resistance to flow due to its straight-through flow design, but is more prone to water hammer than the lift check. Swing and lift check valves generally are only suited for horizontal installations, unless specifically configured for vertical installation.

(f) Water pressure regulating valves are used in the chilled water system to limit the water supply pressure to equipment within acceptable levels. The two common types of water pressure regulating valves include the direct-acting type and the pilot-operated type. The direct-acting regulator consists of an inner valve connected to a diaphragm. The diaphragm is held in position by a spring that is externally adjustable to give the desired downstream reduced pressure. The direct-acting regulating valve is simple and relatively inexpensive, but is not capable of maintaining constant downstream pressures if the upstream pressure varies or if the flow rate varies significantly. The pilot-operated regulator is more accurate than the direct-acting type, as it employs a small direct-acting valve (pilot valve) that maintains a constant pressure on the main valve diaphragm. Variations in upstream pressure have little effect on the resulting downstream pressure.

k. *Piping*. Piping 2 inches and smaller used in chilled water systems is typically standard weight, continuous weld steel pipe with threaded joints and cast iron fittings. In addition, Type L hard copper pipe can be used in this size range. Copper piping uses soldered joints with wrought copper fittings. For chilled water piping larger than 2 inches, steel pipe conforming to American Society for Testing and Materials (ASTM) A 53, Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless (1999), is used. Joint types for this size of pipe are welded, flanged, or grooved. Fittings for ASTM A 53 type pipe are wrought steel, cast iron, and malleable or ductile iron.